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POTENTIAL BENEFITS OF NAVY DIVE COMPUTER USE IN SHIPS HUSBANDRY DIVING: ANALYSIS OF DIVES CONDUCTED AT PUGET SOUND NAVAL SHIPYARD

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19. ABSTRACT
Generation III Air Navy Dive Computers (AIR III) were used to record 315 ships husbandry dives conducted by divers breathing air at the Puget Sound Naval Shipyard from November 2007 to January 2008. For each profile, decompression status was assessed from the air tables in *Rev. 6* of the *U.S. Navy Diving Manual* and from the AIR IIIs. Thirty-five dives were repetitive dives (within 12 hours of a previous exposure), so 280 are distinct profiles for analysis. According to probabilistic models, the average predicted risk of decompression sickness for these profiles was low (<1%), as expected. The majority of dives ended because the assigned work was completed, not because the no-stop limits for the maximum depth were reached. Two 34 fsw profiles were of moderate risk when evaluated by both USN93 and BVM-3. These two profiles exceeded the *Rev. 6 U.S. Navy Diving Manual* no-stop limits, and one of them required five minutes of decompression per the AIR III record. More than 10% of the dives were conducted at or beyond the no-stop limits for *Rev. 6* of the *Diving Manual*; divers would have directly benefited from using AIR IIIs on these dives. The AIR IIIs will also benefit these divers in cases where a diver needs to make a downward excursion (tool recovery, etc.), but until divers are allowed to dive per the guidance of the AIR IIIs, we will be unable to fully tabulate the benefits. A future AIR III benefit for divers will be a reduction in data entry when the Navy Dive computer profiles are downloaded into the Dive Recording System, an expected by-product from development of the Topside Decompression Monitor.

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INTRODUCTION

To support the multilevel nature of Naval Special Warfare (NSW) diving, the U.S. Navy developed a diver-worn decompression computer, the Navy Dive computer (NDC),[1] which was created to support dives in which the diver switches back and forth between air and a rebreather (MK 16 MOD 0) that maintains a nominal diver-inspired oxygen partial pressure (PO_2) of 0.75 atmospheres (atm). The NDC was approved for use by select NSW commands on 25 January 2001.[2] Newer versions of the NDC have been created,[3] including a version (the AIR III) specifically requested by Naval Sea Systems Command (NAVSEA) to support Air diving.[4,5] The Generation III NDC for NSW (NSW III) is on the Authorized for Navy Use list.[6]

To expand the community of Navy divers approved to use the NDC, particularly to include those who routinely dive within the no-stop limits and to facilitate acceptance of the NDC by these divers, it is necessary to illustrate the benefits that use of these devices can provide. Ships husbandry divers, who operate in shallow water with depth excursions dictated by the nature of their tasking, constitute one class of divers who might expect to find a large benefit from NDC use.

The decompression guidance provided by the NDCs is updated every second from the actual prevailing depth and consequently differs from that obtained from conventional tables, which presume a square profile with bottom time spent at the maximum depth attained in the dive. Guidance from tables also incorporates additional safety enhancements from rounding up depths and bottom times. In most cases the guidance based on actual real-time information allows either more bottom time or less decompression obligation than guidance obtained from conventional tables. However, at the shallow depths the no-stop limits for the VVAL-18 Thalmann algorithm are significantly shorter. This shortening of the no-stop limits has concerned the ships husbandry community about accepting new decompression tables.[1] Records from actual ships husbandry dives afford an opportunity to examine the trade-offs between decreased no-stop limits of the new algorithms and the increased bottom times that would be allowed by the real-time implementation in the NDC, all in the context of no-stop diving. It was expected[7] that the changes in depth that occur while ships husbandry is performed would offset the shortening of the no-stop limit.

From November 2007 until January 2008, divers at the Puget Sound Naval Shipyard (PSNS) carried AIR III NDCs[1,5] to record their depth-time profiles. These profiles were analyzed to determine the benefits and constraints on their diving that would have occurred if the AIR IIIs had been used to determine the no-stop limits for these dives.

METHODS

DATA

Records from AIR IIIs were available for 315 PSNS dives. Thirty-five of these dives were repetitive dives (within 12 hours of a previous dive) and were combined into multidive profiles, a procedure leaving 280 distinct profiles to be analyzed and compared.

ANALYSIS

We compared the remaining no-stop times allowed by the new VVAL-18M Navy Air Tables at the maximum logged or recorded depth for each dive to the corresponding remaining no-stop time (RNST) at the maximum recorded depth calculated by NDC/VVAL-18. The logged depth was used when it was within a few feet of the recorded maximum depth, as this was the gauge being used for the tables; the recorded depth was substituted if the logged max depth and recorded depth differed by more than a few feet. In most cases when the logged and recorded max depths disagreed, the logged depths (and bottom times) matched those of another dive being conducted at the same time and were considered data entry errors.

The start time of a dive as well as the max depth and bottom time were used to match up the smooth log entries with the AIR III recorded profiles for a given diver. The consistency of the time offset over all matching dives between the two sources of information was used as a measure of successful profile matching. In the matching process the maximum depths and bottom time comparisons were looking for roughly equivalent values. The maximum depth comparisons were considering the differences in sensor position and gauge accuracies, while the bottom time comparisons needed to account for the differences in definition of bottom time from the smooth log and total dive time from the AIR III records. The smooth logs were provided from the Dive Reporting System (DRS), the database used by the Navy to log all dives conducted.

In this analysis the no-stop limits used for comparison with the AIR IIIs are the most liberal values possible from either Table 9-7 (No-Decompression Limits and Repetitive Group Designators for Air No-Stop Decompression Dives) or Table 2A-1 (No-Decompression Limits and Repetitive Group Designators for Shallow Water Air No-Stop Decompression Dives) of the *U.S. Navy Diving Manual (Rev. 6)*.[8] *Revision 6* was published after this data collection was completed, and it was used for the comparison to show the benefits of the AIR IIIs relative to the new no-stop limits. The new air decompression tables in *Rev. 6* replace Standard Air Tables that have appeared in all versions of the *U.S. Navy Diving Manual* since 1959, and since some of these no-stop limits differ, diver compliance with the new limits was not expected.

The AIR IIIs record dive profile information including time and date of the dive and depth at one-second intervals, information that can be downloaded to a personal computer.

Presently, this data can be accessed only by using the proprietary Cochran Analyst software. When the AIR IIIs were downloaded, manufacturer-supplied Navy Master Edition Analyst version 4.01n software (Cochran Consulting Inc.; Richardson, TX) was used to convert the proprietary data file format into two comma-separated variable (cvs) text files for depth and temperature for each dive. This Navy Master Edition of the Analyst software is also capable of modifying the settings of the AIR IIIs. Navy Experimental Diving Unit (NEDU) software was then used to convert the comma-delimited files to Augmented NMRI Standard Format[9] so that the probabilistic models could be processed.

The USN93[10,11] and BVM3[12] probabilistic models were used to estimate the risks of decompression sickness [P(DCS)] for the recorded dives.

RESULTS

Table 1 summarizes the dive recordings. The summary data include the serial numbers of the AIR III, the dive numbers according to the AIR III, the max depths and bottom times from the smooth log, the max depths and dive times from the AIR III, and the predicted risks for the profiles from both USN93 and BVM3. In a few cases, a single smooth log record matches up with multiple AIR III profiles; in these cases the cells in the table were expanded vertically to cover the rows from the multiple AIR III dives. Unfortunately, some AIR III profiles could not be matched up with smooth log records; this is noted in the smooth log columns.

For the single dives (or first dives of repetitive diving sequences), 29 dives exceeded the *Rev. 6* no-stop limits for the maximum depth by more than the ascent time. Twenty-seven of these dives (except two dives mentioned in the next paragraph) were within the no-stop limits of the AIR III, a result illustrating the efficiency provided by real-time decompression calculation.

In two cases an AIR III called for decompression that did not occur. The first was Dive 10 for X010018, a dive that was logged as 49 fsw for 101 minutes and had nine minutes of decompression prescribed by the AIR III. The second case was Dive 3 for X010021, a dive that was logged as 34 fsw for 284 minutes and had five minutes of decompression prescribed by the AIR III. Notably, a dive conducted at the same time and also logged as 34 fsw for 284 minutes (Dive 5 for X010025) had no AIR III prescribed decompression, as the diver had spent more time at depths shallower than the maximum, a circumstance again illustrating the efficiency provided by the AIR III. It should be noted, however, that these three dives returned among the highest estimated P(DCS) of all the dives recorded. The long, shallow no-stop limits of the Standard Air Tables have high estimated P(DCS), and air no-stop limits at shallow depths have been shortened in *Rev. 6*. All three of these dives exceeded the new no-stop limits tabulated in *Rev. 6* for the logged maximum depths and bottom times.

Table 1.
Summary of recorded dive profiles.

AIR III Serial Number	AIR III Dive Number	Smooth Log		AIR III Record		P(DCS) %	
		Max Depth	Bottom Time	Max Depth	Dive Time	USN93	BVM3
X010003	45	10	23	9.9	23.9	0.04	0.00
X010003	46	30	62	32.0	60.2	0.62	0.24
X010003	47	28	149	27.8	148.6	0.82	0.36
X010003	48	32	38	33.2	34.8	0.17	0.02
X010003	49	98	12	100.0	10.5	0.71	0.53
X010003	50	103	17	103.4	16.4	0.84	0.73
X010003	51	42	90	41.7	81.6	0.64	0.23
X010003	52	17	61	47.1	58.4	0.14	0.00
X010003	53	64	52	68.6	34.5	0.68	0.40
X010003	53-54[1]			28.2	15.4	0.75	0.40
X010003	55	44	98	48.5	97.1	1.11	0.55
X010003	56	44	87	45.9	85.8	0.90	0.40
X010003	57	25	19	31.1	17.9	0.17	0.03
X010003	58	35	39	35.5	36.3	0.34	0.10
X010003	59	81	32	83.9	30.8	1.25	1.18
X010003	60	50	31	58.4	33.3	0.85	0.48
X010003	61	78	43	77.8	42.9	1.92	1.61
X010003	62	52	62	55.1	62.3	1.35	0.94
X010004	46	50	21	48.7	20.0	0.40	0.19
X010004	47	56	54	56.4	54.7	0.38	0.02
X010004	48	30	51	30.1	52.0	0.44	0.16
X010004	49	32	71	38.4	63.9	0.22	0.06
X010004	50	30	22	40.9	25.3	0.18	0.04
X010004	51	60	16	58.1	15.0	0.54	0.32
X010004	52	41	61	40.9	60.5	0.95	0.46
X010004	53	43	92	40.4	88.9	0.71	0.26
X010004	54	35	182	35.9	84.7	0.08	0.00
X010004	54-55[1]			40.6	34.8	0.26	0.05
X010004	56	69	44	71.0	44.1	1.13	0.87
X010004	57	46	97	45.6	99.6	1.54	0.56
X010004	58	68	52	70.2	54.6	2.15	1.81
X010004	59	25	51	31.5	49.7	0.29	0.06
X010004	60	28	31	26.4	33.4	0.06	0.00
X010004	61	41	96	40.9	63.4	0.50	0.17
X010004	62	42	98	42.4	96.0	1.20	0.44
X010004	63	7	65	11.9	36.1	0.00	0.00
X010004	63-64[1]			6.5	4.1	0.00	0.00
X010004	65	37	164	49.4	160.9	1.70	1.11
X010005	47	10	23	10.0	23.9	0.04	0.00
X010005	48	30	86	35.3	85.1	0.48	0.12

[1]A hyphen between two numbers indicates a repetitive dive; info on this line is for the end of the last dive.

Table 1.
Cont.

AIR III Serial Number	AIR III Dive Number	Smooth Log		AIR III Record		P(DCS) %	
		Max Depth	Bottom Time	Max Depth	Dive Time	USN93	BVM3
X010005	49	30	50	22.4	17.6	0.11	0.01
X010005	49-50[1]			32.8	13.9	0.37	0.05
X010005	51	33	83	32.9	81.2	0.14	0.02
X010005	52	35	118	33.7	111.4	0.25	0.03
X010005	53	32	39	29.8	35.9	0.22	0.02
X010005	54	35	67	30.3	70.1	0.60	0.24
X010005	55	35	102	21.6	100.8	0.11	0.00
X010005	56	38	16	39.2	15.9	0.18	0.03
X010005	57	28	107	46.2	106.2	0.51	0.13
X010005	58	34	92	33.5	91.7	0.55	0.15
X010005	59	45	99	45.3	39.1	0.46	0.19
X010005	59-60[1]			45.5	59.0	1.21	0.50
X010005	61	24	69	23.9	68.0	0.10	0.00
X010005	62	NOT FOUND		5.8	104.4	0.00	0.00
X010005	63	NOT FOUND		32.9	2.7	0.09	0.01
X010005	64	35	112	34.8	110.8	0.79	0.15
X010005	65	8	91	9.9	91.7	0.00	0.00
X010005	66	7	10	6.7	9.5	0.00	0.00
X010005	67	9	84	8.9	63.7	0.00	0.00
X010005	67-68[1]			7.9	5.3	0.00	0.00
X010006	46	NOT FOUND		30.9	57.7	0.34	0.08
X010006	47	44	115	45.0	99.7	1.28	0.53
X010006	47-48[1]			41.9	16.5	1.54	0.60
X010006	49	44	72	47.1	67.8	1.05	0.35
X010006	50	44	97	44.8	95.9	1.31	0.62
X010006	51	44	43	44.4	43.4	0.17	0.01
X010006	52	44	90	42.7	15.0	0.18	0.05
X010006	52-53[1]			43.3	72.9	0.87	0.20
X010006	54	25	314	30.8	314.5	1.73	1.65
X010006	55	28	14	27.0	14.8	0.15	0.02
X010006	56	32	27	34.0	23.9	0.21	0.05
X010006	57	66	28	69.5	28.6	1.16	1.08
X010006	58	58	44	59.4	44.5	0.79	0.29
X010007	47	44	98	48.9	101.8	1.34	0.63
X010007	48	44	72	50.0	68.6	1.08	0.51
X010007	49	44	101	49.5	27.0	0.34	0.05
X010007	49-50[1]			48.8	71.7	1.40	0.48
X010007	49-50-51[1]			44.7	10.4	1.52	0.40
X010007	52	44	93	45.6	23.1	0.38	0.06
X010007	52-53[1]			48.2	65.3	1.03	0.34
X010007	54	44	88	43.0	88.3	0.87	0.25
X010007	55	34	62	34.0	61.5	0.44	0.06

Table 1.
Cont.

AIR III Serial Number	AIR III Dive Number	Smooth Log		AIR III Record		P(DCS) %	
		Max Depth	Bottom Time	Max Depth	Dive Time	USN93	BVM3
X010007	56	30	33	29.4	35.0	0.28	0.05
X010007	57	52	12	52.4	10.4	0.37	0.18
X010007	58	38	87	37.1	86.3	0.80	0.27
X010007	59	58	54	58.4	53.0	0.41	0.07
X010007	60	34	105	38.9	9.8	0.63	0.31
X010007	60-61[1]	8	79	38.9	65.2	0.24	0.08
X010007	62			11.0	77.2	0.01	0.00
X010007	63	11	56	10.8	54.2	0.04	0.00
X010008	50	30	57	31.9	59.6	0.34	0.08
X010008	51	29	119	32.2	117.5	0.46	0.08
X010008	52	8	91	13.3	90.5	0.00	0.00
X010009	50	30	86	31.4	77.0	0.44	0.11
X010009	51	71	17	66.4	11.8	0.58	0.38
X010009	52	48	46	47.6	44.7	0.92	0.64
X010009	53	32	56	30.9	58.1	0.35	0.08
X010009	54	65	16	65.5	14.3	0.51	0.30
X010009	55	55	8	54.0	7.3	0.35	0.19
X010009	56	58	56	59.9	60.8	1.31	0.71
X010009	57	46	129	41.3	86.3	0.66	0.24
X010009	57-58[1]	45	99	36.2	47.5	1.17	0.36
X010009	59			44.5	37.2	0.41	0.00
X010009	59-60[1]	48	84	44.0	59.0	1.07	0.39
X010009	61			44.7	83.9	0.81	0.34
X010009	62	25	93	39.4	71.5	0.57	0.22
X010009	63	38	20	39.9	20.8	0.39	0.11
X010009	64	30	11	33.7	10.6	0.24	0.08
X010009	65	40	10	42.2	5.5	0.17	0.05
X010009	66	75	27	74.2	24.9	0.85	0.72
X010009	67	50	22	51.5	20.0	0.39	0.14
X010009	68	67	37	66.6	32.9	0.34	0.12
X010009	69	49	111	49.4	68.4	0.70	0.25
X010009	69-70[1]			10.1	10.7	0.70	0.25
X010009	69-70-71[1]			49.1	36.9	1.29	0.52
X010010	45	33	107	33.5	102.7	0.22	0.03
X010010	46	35	68	55.1	61.3	0.29	0.04
X010011	46	15	39	10.2	3.3	0.00	0.00
X010011	46-47[1]			14.2	20.0	0.02	0.00
X010011	48	42	11	42.6	10.1	0.19	0.04
X010011	49	42	34	73.4	35.2	0.54	0.19
X010011	50	60	22	65.2	15.2	0.41	0.18
X010011	51	28	11	26.2	11.0	0.17	0.03

Table 1.
Cont.

AIR III Serial Number	AIR III Dive Number	Smooth Log		AIR III Record		P(DCS) %	
		Max Depth	Bottom Time	Max Depth	Dive Time	USN93	BVM3
X010011	52	35	30	44.3	30.1	0.37	0.13
X010011	53	44	12	44.3	10.9	0.24	0.09
X010011	54	NOT FOUND		26.0	10.3	0.17	0.04
X010011	55	66	17	68.0	16.1	0.71	0.55
X010011	56	54	23	53.6	23.0	0.57	0.38
X010012	45	32	39	29.7	28.6	0.19	0.03
X010012	46	35	67	30.3	70.1	0.59	0.23
X010012	47	35	102	25.0	100.0	0.21	0.01
X010012	48	28	107	27.1	41.7	0.20	0.01
X010012	48-49[1]			27.2	30.2	0.48	0.04
X010012	50	34	29	31.1	28.2	0.30	0.08
X010012	51	51	16	51.0	16.0	0.19	0.02
X010012	52	50	45	49.9	45.2	0.30	0.11
X010012	53	55	38	54.8	36.7	0.79	0.50
X010012	54	8	45	58.5	43.5	0.22	0.08
X010012	55	7	69	6.9	48.7	0.00	0.00
X010012	57	19	57	19.4	56.4	0.18	0.01
X010015	2	34	92	34.2	89.1	0.18	0.00
X010015	3	20	100	19.9	97.9	0.08	0.00
X010015	4	25	315	31.7	315.2	1.77	1.69
X010015	5	35	74	45.8	74.9	0.71	0.33
X010015	6	32	27	43.6	23.9	0.27	0.07
X010015	7	66	45	68.4	45.9	1.46	0.99
X010015	8	45	63	41.0	62.4	0.19	0.02
X010015	9	72	13	71.6	10.0	0.50	0.33
X010015	10	49	101	53.6	100.2	1.89	1.07
X010017	1	60	52	60.4	55.0	0.66	0.28
X010017	2	35	133	55.4	32.1	0.05	0.00
X010017	2-3[1]			51.1	86.4	0.26	0.06
X010017	4	58	6	50.4	6.9	0.30	0.13
X010017	5	30	321	49.8	311.0	0.43	0.13
X010017	6	45	51	28.5	48.8	0.43	0.10
X010017	7	30	100	51.4	102.0	0.31	0.07
X010017	8	30	57	50.8	55.5	0.39	0.08
X010017	9	30	137	53.8	135.7	0.71	0.16
X010017	10	33	57	48.8	57.5	0.30	0.12
X010017	11	35	51	55.1	51.5	0.10	0.00
X010017	12	28	107	52.7	3.8	0.25	0.11
X010017	12-13[1]			30.0	99.4	0.50	0.12
X010017	14	34	84	51.6	84.4	0.21	0.02
X010017	15	51	44	50.8	42.4	0.14	0.01

Table 1.
Cont.

AIR III Serial Number	AIR III Dive Number	Smooth Log		AIR III Record		P(DCS) %	
		Max Depth	Bottom Time	Max Depth	Dive Time	USN93	BVM3
X010017	16	50	45	51.4	45.2	0.31	0.12
X010017	17	NOT FOUND		52.8	11.0	0.38	0.15
X010017	18	32	152	57.1	149.3	1.12	0.52
X010017	19	35	69	37.9	72.4	0.46	0.12
X010017	20	49	92	52.6	90.6	1.76	1.15
X010017	21	49	101	51.6	99.3	1.94	1.43
X010018	1	57	11	56.8	9.0	0.37	0.21
X010018	2	29	61	28.7	60.7	0.47	0.14
X010018	3	32	33	31.7	32.1	0.32	0.09
X010018	4	72	33	71.7	32.4	0.52	0.26
X010018	5	67	33	66.6	32.2	1.04	0.84
X010018	6	36	44	37.1	44.1	0.55	0.27
X010018	7	47	24	46.6	21.3	0.45	0.22
X010018	8	52	27	52.0	9.9	0.32	0.12
X010018	9	78	39	78.4	37.0	1.45	1.35
X010018	10	49	101	51.4	100.7	2.10	1.62
X010019	4	43	21	44.1	20.4	0.14	0.02
X010019	5	30	42	31.5	45.8	0.43	0.16
X010019	6	30	22	27.6	24.0	0.21	0.04
X010019	7	32	45	33.7	45.4	0.17	0.03
X010019	8	48	46	47.5	44.8	0.93	0.64
X010019	9	65	16	65.3	13.8	0.54	0.32
X010019	10	72	33	72.5	31.7	0.64	0.38
X010019	11	46	115	40.0	86.0	0.66	0.25
X010019	11-12[1]			38.4	49.4	1.18	0.38
X010019	13	45	100	47.0	100.8	1.34	0.62
X010019	14	48	84	45.7	80.1	0.81	0.29
X010019	15	38	20	38.6	16.7	0.31	0.11
X010019	16	30	11	31.0	10.5	0.22	0.06
X010019	17	41	96	40.6	63.3	0.48	0.17
X010019	18	42	98	43.1	99.7	1.14	0.44
X010019	19	72	13	71.4	9.7	0.50	0.32
X010019	20	35	55	35.1	57.8	0.31	0.02
X010019	21	78	40	76.9	39.1	1.68	1.53
X010019	22	52	62	54.9	61.9	1.13	0.67
X010020	1	35	133	33.9	13.6	0.16	0.03
X010020	1-2[1]			40.1	101.6	0.52	0.10
X010020	3	30	311	34.6	129.0	0.29	0.02
X010020	4			6	0.85	Unable to access	
X010020	3-5[1]			31.6	5.6	0.43	0.05

Table 1.
Cont.

AIR III Serial Number	AIR III Dive Number	Smooth Log		AIR III Record		P(DCS) %	
		Max Depth	Bottom Time	Max Depth	Dive Time	USN93	BVM3
X010020	6	30	51	30.5	52.0	0.44	0.16
X010020	7	30	100	33.5	50.1	0.05	0.00
X010020	7-8[1]			32.1	2.6	0.13	0.01
X010020	9	28	136	32.4	7.0	0.01	0.00
X010020	9-10[1]			29.6	7.0	0.12	0.01
X010020	11	32	119	34.4	118.5	0.46	0.08
X010020	12	33	35	35.9	35.9	0.15	0.03
X010020	13	35	118	34.6	115.1	0.32	0.03
X010020	14	58	61	60.4	62.0	1.37	0.75
X010020	15	46	72	45.1	70.7	1.33	0.55
X010020	16	46	98	44.7	63.0	0.71	0.37
X010020	17	45	43	69.9	38.4	0.45	0.19
X010020	18	25	51	30.4	49.7	0.30	0.06
X010020	19	28	31	26.5	30.0	0.14	0.00
X010020	20	25	57	26.6	69.7	0.09	0.00
X010020	21	36	44	37.2	44.1	0.55	0.28
X010020	22	34	11	33.8	9.8	0.10	0.01
X010020	23	80	24	80.5	22.9	0.75	0.28
X010020	24	50	22	51.9	20.6	0.38	0.13
X010020	25	37	153	36.7	153.6	1.10	0.13
X010020	26	52	62	51.9	62.3	1.09	0.59
X010020	27	49	101	50.6	101.2	1.40	0.70
X010021	2	37	55	36.5	50.9	0.47	0.16
X010021	3	34	284	34.2	283.8	4.12	3.59
X010021	4	32	71	46.5	68.4	0.23	0.06
X010021	5	30	22	39.0	24.8	0.17	0.03
X010021	6	30	50	33.1	13.9	0.25	0.04
X010021	7	36	68	35.8	70.7	0.19	0.03
X010021	8	17	61	25.0	59.3	0.33	0.00
X010021	9	45	100	47.4	100.6	1.18	0.62
X010021	10	45	56	45.1	54.3	0.64	0.33
X010021	11	42	90	42.4	87.5	1.26	0.22
X010021	12	71	41	72.8	40.0	1.59	1.07
X010021	13	31	26	30.8	22.9	0.18	0.04
X010021	14	34	11	35.6	10.4	0.12	0.02
X010021	15	78	42	78.7	41.9	1.97	1.79
X010021	16	48	98	64.9	96.3	1.28	0.47
X010022	2	35	121	36.8	121.3	0.65	0.10
X010022	3	44	97	38.7	32.1	0.11	0.00
X010022	3-4[1]			50.3	65.3	1.22	0.54
X010022	5	44	86	49.4	53.5	0.57	0.23
X010022	5-6[1]			48.5	36.9	1.40	0.54

Table 1.
Cont.

AIR III Serial Number	AIR III Dive Number	Smooth Log		AIR III Record		P(DCS) %	
		Max Depth	Bottom Time	Max Depth	Dive Time	USN93	BVM3
X010022	7	44	24	47.8	22.1	0.29	0.08
X010022	8	44	98	46.6	28.3	0.21	0.00
X010022	8-9[1]			50.1	73.8	1.40	0.51
X010022	10	46	101	43.9	101.3	1.23	0.67
X010022	11	35	74	76.8	75.0	1.08	0.63
X010022	12	15	15	9.1	8.1	0.01	0.00
X010022	13	35	85	35.5	84.3	0.84	0.33
X010022	14	63	44	65.0	54.1	0.61	0.30
X010022	15	78	40	77.5	40.0	1.76	1.60
X010022	16	19	34	18.6	33.6	0.11	0.00
X010023	5	39	83	34.2	80.6	0.30	0.03
X010023	6	58	6	52.9	6.8	0.36	0.18
X010023	7	35	153	33.7	152.4	0.31	0.01
X010023	8	35	124	25.1	123.7	0.53	0.11
X010023	9	55	9	55.0	7.2	0.35	0.18
X010023	10	98	27	100.4	26.4	1.61	1.47
X010023	11	30	176	14.7	11.5	0.02	0.00
X010023	11-12[1]			54.3	34.6	0.91	0.27
X010023	12	44	86		54.5	0.88	0.27
X010023	12-13[1]			46.7	36.6	1.28	0.25
X010023	15	44	97	45.9	94.9	1.26	0.41
X010023	16	44	87	44.2	86.2	0.74	0.34
X010023	17	35	39	34.9	158.4	0.67	0.20
X010023	18	35	127	40.8	126.6	1.03	0.40
X010023	19	66	42	70.0	41.6	1.14	0.82
X010023	20	18	34	18.0	33.6	0.10	0.00
X010024	3	30	72	56.7	114.7	1.86	1.37
X010024	4	98	12	98.1	10.4	0.68	0.49
X010024	5	103	15	102.6	14.2	0.78	0.68
X010024	6	42	90	40.7	81.6	0.57	0.18
X010024	7	44	93	37.6	33.1	0.19	0.00
X010024	7-8[1]			48.5	60.3	1.18	0.30
X010024	9	44	98	53.8	95.4	1.28	0.62
X010024	10	44	24	46.2	22.2	0.30	0.10
X010024	11	35	30	38.1	72.3	0.53	0.17
X010024	12	44	87	44.7	88.4	1.01	0.43
X010024	13	34	66	31.7	63.6	0.50	0.08
X010024	14	35	127	41.0	123.9	0.97	0.30
X010024	15	52	12	54.2	10.3	0.42	0.24
X010024	16	57	28	56.9	28.4	0.82	0.66
X010024	17	44	23	44.4	22.7	0.43	0.20

Table 1.
Cont.

AIR III Serial Number	AIR III Dive Number	Smooth Log		AIR III Record		P(DCS) %	
		Max Depth	Bottom Time	Max Depth	Dive Time	USN93	BVM3
X010024	18	7	69	6.9	38.4	0.00	0.00
X010024	19			5	0.08	Unable to access	
X010024	20	10	15	10.5	13.5	0.03	0.00
X010024	21	9	85	8.0	65.5	0.00	0.00
X010024	21-22[1]			9.4	5.8	0.00	0.00
X010025	3	53	55	52.6	57.7	0.41	0.06
X010025	4	57	11	56.5	9.0	0.37	0.20
X010025	5	34	284	33.9	283.7	4.01	3.49
X010025	6	28	158	32.7	30.0	0.03	0.00
X010025	6-7[1]			35.8	111.1	0.71	0.15
X010025	8			5	0.05	Unable to access	
X010025	9	32	45	33.7	45.4	0.17	0.03
X010025	10	71	17	70.8	15.2	0.54	0.31
X010025	11	41	61	40.7	60.5	0.86	0.38
X010025	12	43	33	44.2	33.2	0.60	0.19
X010025	13	38	16	37.1	15.7	0.17	0.03
X010025	14	69	44	68.5	44.0	0.97	0.52
X010025	15	46	97	45.7	101.8	1.02	0.44
X010025	16	46	72	45.5	72.1	1.27	0.62
X010025	17	46	66	45.7	67.7	0.80	0.44
X010025	18	68	52	70.8	62.8	1.52	0.59
X010025	19	25	93	39.9	72.9	0.71	0.19
X010025	20	40	10	41.3	11.8	0.31	0.06
X010025	21	31	26	31.5	23.7	0.18	0.03
X010025	22	72	34	72.6	36.1	1.29	0.99
X010025	23	67	37	69.5	36.6	0.91	0.72
X010025	24	78	42	75.6	42.5	1.61	1.41
X010025	25	52	60	51.3	57.6	0.83	0.32
X010025	26	49	111	49.0	72.4	0.77	0.33
X010025	26-27[1]			49.2	36.7	1.35	0.54

The two highest risk profiles conducted according to both USN93 and BVM3 were both to 34 fsw and exceeded the *Rev. 6* no-stop limits. The predicted risks for these profiles are 4.12% and 4.01% per USN93, and 4.01% and 3.49% per BVM3. The riskier of these two dives required five minutes of decompression according to the AIR III (same profile mentioned above in paragraph 3 of RESULTS). The second profile would have been allowed by the AIR III. The next highest predicted risk was 2.15% by USN93 and 1.81% by BVM3; both of these risks are lower than that of a no-stop 60 fsw profile for 60 minutes. The average predicted risk of the recorded profiles was 0.66% for USN93 and 0.33% for BVM3.

PROBLEMS

Software

Some limitations are associated with working with proprietary software. Data downloads were hampered by removing the transfer dive data to the DAN (Divers Alert Network) feature in the versions of Analyst that support the AIR III NDCs. NEDU is no longer able to output series of dives from Analyst and must display each dive before selecting to output the recorded data for the dive to depth and temperature comma-delimited files. The labor requirements are now proportional to the number of dives recorded; previously they were related to the number of NDCs used. There is now a transfer to Cochran option for the profiles, but this transfer creates an error when an Internet connection is not present. Internet connectivity is not available for non–Navy Marine Corps Intranet (non-NMCI) machines, and Analyst is not approved for use on NMCI machines.

Analyst consistently crashes for Profile 1 for AIR III S/N X010022 and Profile 45 for AIR III S/N X010004. Many inconsistent crashes also occurred while investigators were attempting to view and transfer the profiles.[5] Cochran reports that it did not experience problems with either of the two above-mentioned profiles when it downloaded the AIR IIIs.

Three AIR III dives have assigned numbers for which Analyst will not display the profile; when we attempted to display the profile, the message was that the dive was too short. Cochran Undersea Technologies was contacted, and their response was that the dive counter in the AIR III is incremented when the AIR III descends through the start depth setting (a configurable parameter) after the interval length (another configurable parameter), and that Analyst is not able to graph a dive if it is less than one minute in duration. The maximum depth of the three dives is 6 feet of seawater (fsw), and the durations are 3 seconds, 5 seconds, and 51 seconds. This information about a profile is available from the Dive History option in Analyst.

AIR III Use

AIR III X010010 was returned to NEDU marked as out of commission (OOC). The verbal complaint was that this AIR III would turn off in mid dive. Once the batteries were changed at NEDU it appeared to work correctly. We believe that the problem was one of battery voltage and was exacerbated by the cold Puget Sound water. After examining the AIR III X010010 and its internal recordings of battery voltage, Cochran Undersea Technologies concurs with this theory. This type of error can be reduced with better diver training on battery change procedures — which are already in place for the NSW IIIs.

Data Matching

Inconsistencies occurred between the dates in the downloaded files and the dates of the corresponding dives in the smooth logs. Table 2 presents the average time offsets. A difference in times recorded in the majority of the computers and those in the smooth logs resulted from the discrepancy between times at NEDU (Central Time) and PSNS (Pacific Time) plus one hour for having crossed a daylight saving time change after the computers were received at NEDU. However, some AIR IIIs differed by up to three days, with one computer being off by 21 days. We can offer no consistent explanation other than the AIR III times had been set while being downloaded to a computer running Analyst with an incorrect date/time setting. All nine of the AIR IIIs with unexpected time offsets were from the first group of 10 that NEDU had purchased from Cochran for the testing reported by Gault[5] and have been used for previous data collection and display. Some of these AIR IIIs were taken to La Maddalena, Italy, to support data collection and may have had their times changed during that operation. The present task was the first use of the second batch of 10 AIR IIIs; this suggests that the time changes occurred prior to NEDU sending the units to PSNS.

In many cases AIR III records were unavailable for dives that were in the smooth logs. While we simply do not know the exact cause of this disparity, we conjecture that these missing records could result from divers forgetting to put on the AIR IIIs before the dive or determining that the AIR III would impede the planned purpose of the dive. For only five dives were there AIR III records for which a matching smooth log was not found: a likely cause is that the AIR III had been dove either by a different diver picking up the wrong AIR III or by someone wishing to check out the unit. For two of the dives it appears that divers wore the wrong AIR III; in the other three cases no matching dive is recorded in the smooth logs with the timing offsets shown in Table 2.

In a majority of the cases where the smooth logs disagreed with the recorded profiles, a dive's max depth, start time, and duration matched an adjacent profile for another diver on the smooth log printout. Such a match occurred for at least 22 dives. One duplicate smooth log entry resulted for a diver: all the pertinent information (start date/time, maximum depth, and bottom time) is identical between the two logs. The AIR III records show that this diver conducted two dives on that day, although clearly not simultaneously. DRS should not allow two entries for a given diver to overlap in time. This type of error can occur when data are copied from the handwritten logs into the DRS system on a computer. Clearly the DRS smooth logs alone are not sufficiently accurate to perform any analysis about the dives being conducted in ships husbandry. The smooth log has an entry for seven divers as Dive ID 03, logged as occurring on 27 November 2007. With the offsets from Table 2, the AIR III records for six of the seven divers in this entry indicate that the dive was performed on 26 November 2007. The seventh diver was not assigned an AIR III. In calculating the time offset for the AIR IIIs, we used the 26 November date as being the correct one. That 27 November date is believed to be an error in DRS, since once the offsets were known for the AIR IIIs, the matching was consistent.

Table 2.
Average time offset between the AIR III recorded time and the date/time from the smooth log. A positive three-hour difference is the expected one between the time zones at NEDU (AIR IIIs programmed) and at PSNS.

AIR III Serial Number	Time Offset		
	Direction	Days	Hours:Minutes
X010003	—	3	4:03
X010004	—	2	4:16
X010005	—	2	0:27
X010006	—	21	6:58
X010007	—	1	5:20
X010008	+		6:21
X010009	—		19:47
X010010	—		23:35
X010011	+		3:14
X010012	—		22:33
X010015	+		3:15
X010017	+		3:09
X010018	+		3:14
X010019	+		3:15
X010020	+		3:14
X010021[1]	+		3:15
X010022	+		3:14
X010023	+		3:18
X010024[1]	+		3:16
X010025	+		3:13

[1] These two AIR IIIs each have one dive off by an extra two hours; the dive is logged as starting on the same date at the same time. This outlier was not included in their average offset.

DISCUSSION

A potential benefit of using the AIR IIIs is the increased no-stop time due to the multilevel nature of ships husbandry diving. However, most of the present dives did not approach the no-stop limits, as those in our analysis of the CVN 76 ships husbandry dives did.[7] The majority of the dives reported here ended long before reaching the no-stop limit, presumably because the work was completed. Reporting the extra no-stop time made available by the AIR III would falsely convey the magnitude of the benefit that the AIR IIIs have to offer these ships husbandry divers.

Of the nonrepetitive dives reported here (249 profiles + 31 first dives of sequences), 29 exceeded the no-stop limits for the tabulated max depth (or the recorded maximum, if max depth appears to be a data entry error) by more than the ascent time. Fifteen dives are within five minutes of the no-stop limit that may have been called short due to the table limits. Thus more than 10% of the dives conducted would have benefited from using the AIR III's calculations of the no-stop limits rather than using the tables in *Rev. 6*, even with the addition of the shallow water tables.

If the guidance of the AIR IIIs was being used to govern the dive durations to remain within no-stop limits, only two of the 315 dives performed would have been stopped earlier than they were, and by less than 10 minutes. Both of these dives would also have exceeded the new no-stop limits of *Rev. 6*.

As expected, most of the predicted risks for the conducted dives are low; a few higher risk long, shallow dives have been the subjects of much scrutiny.[13]

The AIR IIIs would offer the benefit of not penalizing the diver for deep excursions to recover a dropped tool or part or to take a quick view of circumstances. This benefit is hard to quantify: no log exists of dives having been cut short after a diver made such an excursion or of an additional diver having been put into the water to make such a recovery.

A future benefit that AIR IIIs can make is to improve the reporting of dive profiles by having their output integrated into the DRS. With automated data transfer routines, the maximum depth and dive times can easily be filled in from the records. The type of discrepancies with the maximum depths and bottom times in the smooth log indicate data entry errors when information is transferred from handwritten logs to the computer. This type of error can be removed from the system while the labor required is reduced.

The number of different time offsets between the AIR IIIs and the smooth logs is a troubling observation about the use of the NDCs as the only source of information for the DRS in the future. The time change between NEDU and PSNS was expected; the number of variations was not. It is notable that the second batch of 10 AIR IIIs is all consistently made different by the time change, while those that were acquired previously have varying time settings. Having all of the inconsistencies be for the first 10 AIR IIIs that NEDU had used for data collection and display indicates a need to check the date setting before each of the AIR IIIs is fielded. When attempting to read the dates from the AIR IIIs after the problem was apparent, Analyst did not display the incorrect dates under those AIR IIIs' current settings; the current dates and times could be transferred to the AIR III, but none of the AIR IIIs appeared to be incorrectly configured. It could be that when the profiles were downloaded, the time or date was corrected, or it could be that the date and time values from the AIR III are not what is displayed. Cochran Undersea Technologies indicates that there is an alternate location to view the current time settings of an NDC under the historical stat sheet when the AIR III is being accessed by Analyst. This behavior will need to be investigated. A possible solution for the AIR III's future use is to have the NDC's date and time settings verified each time they are downloaded into the DRS or Topside Decompression Monitor (TDM) system. For now, we will need to explicitly verify the date and time before each trial involving the AIR III.

The changes to the Analyst software that have reduced the amount of automation involved in exporting dive records have increased the level of effort required to analyze profiles collected for the operational dive data collection (ODDC) project. As we seek to collect and analyze larger quantities of dives from each successive effort, it is becoming necessary to automate as much of the process as possible. Cochran Undersea Technologies promises to return the batch processing functionality that existed in v3.0X of Analyst before the upgrade was made to the Generation III NDCs are three years old and are not expected to be fulfilled soon. The Navy's best interest is to obtain direct communication routines now for the NDC and the Dive Data Recorder (DDR; another Cochran product used by ODDC) to reduce the labor overhead and to proceed with the planned integration of these routines into the TDM and possibly the DRS.

CONCLUSIONS

According to probabilistic decompression models for these profiles, the average predicted risk of decompression sickness was low (<1%), as expected. The majority of dives ended because the assigned work was completed, not because the no-stop limits for the maximum depth were approached.

Approximately 10% of the dives were conducted at or beyond the no-stop limits for *Rev. 6* of the *U.S. Navy Diving Manual*; divers would have directly benefited from using AIR IIIs on these dives, as the AIR IIIs would not have decreased the amount of no-stop time available to the diver.

The quality of recorded dive profiles was generally good but was somewhat compromised by differences between logged and recorded maximum depths and dive times. Some of these logging issues may result from computer entry into the DRS postdive rather than from the pen-and-paper method used at the time of the dive.

A final problem that resulted in difficulties correlating the AIR III profiles with the smooth logs was that of incorrectly set dates and times in the AIR IIIs. Correct settings need to be verified before each field data collection effort.

RECOMMENDATIONS

To allow for a more comprehensive assessment of the benefits of the AIR III in fleet use, the AIR IIIs need to be used to prescribe decompression requirements.

To make it more cost effective to use the AIR IIIs and the dive data recorders to collect operational dive data, we recommend purchasing the access routines for these computers from Cochran Consulting to incorporate them in our analysis software. To avoid the presently occurring data entry errors, we also recommend that these access routines be used in the TMD and DRS to directly enter depths and times for a diver.

We will need to investigate the cause of the inconsistent dates and times in these AIR IIIs and to institute a procedure to ensure that all NDCs are set with the correct dates and times to maintain accurate records.

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